ENERGY R&D

INDUSTRIAL HEAT PUMP TECHNOLOGY REVIEW

Prepared for:

Ontario Ministry of Energy
Energy Technology Development

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D I S C L A I M E R

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CURRENT R & D ACTIVITY

1. INTRODUCTION

The electrically-driven heat pump in both its open and closed-cycle configurations offers significant potential for reducing purchased energy in processes such as concentration by evaporation, waste heat recovery for boiler feedwater heating and product drying.

With the exception of lumber drying by dehumidification (about 200 installations) the industrial heat pump has insignificant penetration in Canada in concentration by evaporation processes and waste heat recovery applications. ORF estimates that there are about ten mechanical vapour recompression (MVR) evaporators installed in industrial processes in Canada. The waste heat recovery installations (about 10 - 15 at present) have been largely demonstration projects partially funded by government agencies.

In the United States, the number of industrial heat pump installations, both MVR and Reverse-Rankine closed-cycle no doubt exceed those in Canada by a factor of about ten. Research, development and demonstration efforts are funded largely by the Department of Energy and the Electric Power Research Institute.

This report presents the results of an overview study of current industrial heat pump research and development activities in both Canada and the United States.

2. OBJECTIVE AND SCOPE

The objective of the investigation was to review: current significant research efforts relating to equipment, refrigerants and advanced applications; technical difficulties encountered on NRC funded heat pump demonstration projects and to provide recommendations to the Ministry of Energy on R & D efforts needed to accelerate commercialization of electrically-driven industrial heat pumps.

An earlier investigation [12] sponsored by the National Research Council of Canada had established contact with R & D performers in Canada to provide a brief '*Status and Outlook* for industrial heat pump technology.

The current review was to follow-up with many of the same organizations to update activities and to expand the effort to include contact with relevant organizations in the United States.

The organizations were contacted by telephone with discussions centering on current R & D activities and future plans. Relevant research reports/papers were either cited or provided by the individuals contacted. In many projects, no information could be provided at the time. The following organizations were contacted:

- United States Department of Energy, Washington, D.C.;
- United States Department of Energy, Idaho Falls, Idaho;
- Electric Power Research Institute, Palo Alto, California;
- National Research Council of Canada, Ottawa;
- Ontario Hydro (Research Division);
- Energy, Mines and Resources Canada (Canmet), Ottawa;
- Pulp and Paper Research Institute, Montreal, Québec;
- Institut de Recherche d'Hydro-Québec, Varennes, Québec.

Appendix 1 presents results of the telephone survey identifying the organization and individual contacted, and the current research activity underway.

The review of technical difficulties is based on published information resulting from NRC's Division of Energy, Industrial Heat Pump Program demonstration projects.

3. CURRENT RESEARCH ACTIVITY

United States Department of Energy (D.O.E.)

Industrial Heat Pump research funded by the Department of Energy comes under the auspices of the Industrial Programs office. Research activities are undertaken or supported through National Laboratories at Oak Ridge, Tennessee and Idaho Falls, Idaho.

The research activities within the scope of the current investigation are managed or undertaken through the Idaho National Engineering Laboratory and Department of Energy, Idaho Operations Office. They include:

1. Prototype Design, Construction and Test:

    - the Westinghouse Methanol Rankine Heat Pump;
    - the AirResearch Brayton-Cycle Solvent Recovery System;
    - the Mechanical Technology Inc. Waste-Heat Powered Steam Compression Heat Pump.

2. Comparative Performance Application Evaluation Studies:

    - application of Process Synthesis to assist in identifying desirable heat pump characteristics and thereby allow D.O.E. to select heat pump technologies for development.

The design, construction and testing of the three prototype systems identified in 1. above were initiated by D.O.E. in the mid to late 1970's in line with D.O.E.'s objective

to improve industrial process energy efficiency by means of heat pumps. A brief description of the three systems is included here for the reader's benefit. The prototypes emerging from the program in 1984 had the following specifications which were designed for specific applications, as noted:

Westinghouse Electric [1]

The Reverse-Rankine cycle prototype was designed to extract heat from vapour effluent from a Thermal Mechanical Pulping Unit in a paper mill and to produce clean steam. For this high temperature application, methanol was selected as the working fluid. The final prototype as tested produced steam, with 20°F superheat, at 63 psig. (330°F) in the amount of 32,650 lbm/hr. This represents a thermal output of 30,000,000 Btu/hr. The coefficient of performance was measured to be 4.6 with an inlet waste steam source of 27,700 lbm/hr. at 10 psig (230°F).

AirResearch [2]

The prototype was designed to recover solvents from drying air leaving a magnetic tape drying oven and to return clean, heated air to the ovens. The system, based on a Brayton cycle, was designed to remove 500 lb/hr. of solvent and 72 lb/hr. of water from an 8000 CFM airstream leaving the magnetic tape oven.

The Brayton Cycle Solvent Recovery System consists of a Freon loop (R-11) and a Brayton cycle complete with turbocompressor and heat exchangers. The Freon loop removes heat from the oven airstream and transfers the heat to the clean air before the air enters the oven. (The R-11 loop is pressurized and does not change phase.) The freon is then cooled by the turbine discharge air in a Freon cooler and the process is repeated.

The turbine drives a compressor to raise the pressure and temperature of the solvent laden oven air prior to entry to the freon coolers in the loop and the solvent condenser. The solvent condenses at approximately -60°F.

Mechanical Technology Incorporated (M.T.I.) [3]

The M.T.I. prototype was designed as a waste-heat driven open cycle heat pump. Heat was to be recovered from a waste steam source to evaporate both clean water and R113 to drive a turbine. The turbine then drives a steam compressor

to compress clean water vapour for process steam requirements.

The R113 is the working fluid in the Rankine cycle unit driving the compressor. The R113 vapour is expanded through a turbine, producing shaft work and then is exhausted to a condenser where it is pumped to a preheater/evaporator to complete the cycle.

The steam side is essentially a conventional open cycle steam compressor or mechanical vapour recompressor (MVR).

The prototype used 34,700,000 Btu/hr. of 10 psig waste steam as a heat source and generates 20,900,000 Btu/hr. of clean steam at 25 psig. About 40 percent of the waste steam is used to evaporate R113 while the remaining 60 percent is used to evaporate clean feedwater enroute to the MVR.

A 600 hp turbine running at 3600 rpm drives a high speed centrifugal steam compressor through a gearbox at about 21,000 rpm. The MVR compresses about 22,000 lb/hr. of saturated inlet steam (21.6 psia) to an outlet condition of 40 psia.

D.O.E. Industrial Prototype Status Update

Conversations with Department of Energy staff in March, 1987 revealed that field tests on the M.T.I. and Westinghouse prototypes were never undertaken because arrangements with the selected industrial host sites fell through. Discussions apparently were held between Québec Hydro, D.O.E. and Westinghouse officials regarding a Canadian Pulp and Paper demonstration site. However, Québec Hydro lost interest because of patent restrictions, the details of which were not revealed by the D.O.E. contact.

The M.T.I. unit was designed for installation in a plant that manufactured synthetic fibers but an appropriate site could not be found.

The Brayton Cycle Solvent Recovery System however is slated for installation in a 3M plant in May 1987. The D.O.E. official expressed a wish for a successful demonstration of the Brayton Cycle unit which has the potential for widespread application in U.S. industry where 10 million tons of solvents are used annually. Both economic and environmental considerations dictate some means of solvent recovery.

No doubt bad publicity from early heat pump heat recovery installations in industry coupled with the fact that about 10 years passed from initiation to completion of the D.O.E. heat pump prototypes (including the passing of the

energy crisis) explains the lack of interest by industry in the three systems.

The D.O.E. Heat Pump Program has therefore shifted emphasis from almost exclusively prototype development, construction and testing to include research efforts geared to identifying the proper use for the heat pump in industry. So the D.O.E. has taken a step back and decided to view the heat pump's role in certain processes. The process synthesis industry has been involved now for a couple of years working with both D.O.E. and E.P.R.I. in identifying where and under what circumstances heat pumps make sense in industrial processes.

Process Synthesis [4]

Proper placement of the right kind of heat pump can in many cases reduce the total prime energy used and the energy used by both heating and cooling plants or utilities.

D.O.E. and E.P.R.I. initiated a coordinated effort to study heat pumps in industrial processes from the process synthesizer's point of view employing a technique, popularized by Linnhoff/March, for process energy management, referred to as ' *pinch technology* '.

Pinch technology allows a process synthesizer to:

- determine minimum hot and cold facility or utility energy requirements for any industrial process;

- precisely integrate heat exchangers for minimum energy consumption.

In this method, heat flows in a plant's processes are plotted on a temperature versus heat flow plot. Arrowheads designate the sense of the heat flow. That is, those pointing downward to the left represent streams being cooled; those pointing upward and to the right are streams being heated. Horizontal lines represent evaporating streams. When these process heat flows are added together, and shifted horizontally until they touch, they form a so-called '*composite* ' curve. The point at which they touch is called the ' *process temperature pinch* '. The horizontal distance between the lines at the top and bottom are the minimum heating and cooling utilities respectively for all the processes.

If the horizontal difference between the lines on the composite curve are plotted on the same axes, the ' *grand composite* ' curve results. Where the line touches the vertical axis (the process temperature pinch) the ' *grand composite* ' is divided into two areas. Above the pinch, heat is required; below the pinch heat

must be removed. Reference [5] provides examples of how pinch technology is applied to industrial processes.

When all the processes within a plant requiring heating and cooling are plotted in this manner, one can immediately see that heat pumps must pump heat from below the pinch temperature point to above to be effective (ie. to save energy). This would not be obvious if one only examined a process flow diagram.

In a recent study for D.O.E., ten processes were examined using pinch technology. The pinch temperature ranged from 150°F to 350°F. This range of temperature poses a challenge for current closed cycle heat pumps with R114 as the working fluid. Open cycle heat pumps, however, using fluids from the process directly are less sensitive to pinch temperature extremes. In other words, processes suitable for heat pump applications must have pinch temperatures within the range covered by state-of-the-art heat pumps. Alternatively, new equipment developments must be targeted to operate in the range of pinch temperatures for various processes.

Other Current D.O.E. Heat Pump Research

The Department of Energy have other industrial heat pump research and development underway, including:

- liquid, vapour chemical heat pumps aimed at increasing heat pump delivery temperatures in waste heat driven heat pumps;
- development of a magnetic heat pump which will be built for testing in 1987;
- solid, vapour absorption heat pumps based on materials such as zeolites and steam;
- heat of reaction chemical heat pumps with a test model due for evaluation in 1987.

Electric Power Research Institute (E.P.R.I.)

Industrial heat pump research funded by the Electric Power Research Institute is managed under the Industrial Electrification Program, Non-Metals Applications, specifically the Process Industries area.

Project RP2220 entitled ' *Industrial Heat Pumps* ' has three activities underway

as follows:

- RP2220-01 - Hybrid High COP Heat Pump Application Study;
- RP2220-02 - Heat Pumps in Evaporation;
- RP2220-03 - Heat Pumps in Complex Heat and Power Systems.

Project RP2220-01 is an assessment of the potential technical and economic markets for a hybrid (either waste heat or electrically driven) heat pump and identification of potential industrial demonstration sites. This is, in fact, the prototype originally designed, constructed and laboratory tested by Mechanical Technology Incorporated with funding from the D.O.E.

The unit in its current configuration consists of an Organic Rankine Cycle (freon working fluid) coupled to a steam compressor through a clutch, motor-generator and gearbox. The Hybrid Heat Pump offers considerable flexibility including the ability to:

- operate as a conventional electrically-driven open-cycle heat pump; (ie. electric motor driving compressor rather than an Organic Rankine Cycle);

- operate as a cogeneration system (ie. when the Organic Rankine Cycle's shaft power capability exceeds the steam compressor's power needs - excess power could be converted to electricity by the motor-generator).

By shifting from electric drive to Organic Rankine Cycle Drive, an industrial user can accomplish peak shaving. The cogeneration mode of operation would also allow for peak shaving.

' *Heat Pumps in Evaporation* ' (RP2220-02) is attempting to develop application guidelines and ultimately case studies of electrically-driven MVR's in evaporation processes in the chemical, petroleum, textile, pulp and paper, dairy and food industries. The application guidelines are being developed based on the ' *process synthesis* ' or pinch technology discussed earlier. The principal contractor is Union Carbide with the involvement of Linnhoff/March.

Finally, in RP2220-03, Tensa Technology, a unit of ICI Americas, is applying Pinch Technology to develop a new procedure and software for identifying and assessing heat pump opportunities in complex heat and power systems characteristic of the process industries.

In a recent paper [5] reporting on progress on RP2220-03, Tensa concluded that:

- an optimum heat pump is one that is not only correctly placed in a thermodynamic sense but also of the optimum size and of the right type;

- depending on utility costs, a heat pump with a lower COP may be more economical than one with a higher COP. Higher temperature lifts may result in greater temperature driving forces, decreasing heat exchange areas and cost and more than compensating for increases in compressor costs.

Unlike the Department of Energy, E.P.R.I. concentrate on '*generic*' or application research and do not undertake product development. In the future, case studies will be developed on installations based on the approaches being examined in RP2220.

National Research Council Canada (NRCC)

The Division of Mechanical Engineering, National Research Council Canada, continue industrial heat pump research activities although on a much smaller scale than those under the program formerly managed by the now defunct Division of Energy.

The current research activities [6], [7] are restricted to in-house efforts to design, construct and test a pilot scale steam generating heat pump and to continue work in non-azeotropic refrigerant mixtures. Funding for the work is provided, in part, by EMR, CANMET.

The pilot scale steam generating heat pump will have a thermal output capacity of about 40 kW. Using refrigerant R113, condensing temperatures in the range of 120°C to 145°C, and evaporating temperatures of 50°C to 75°C, will be possible. A Mycom compressor, with water cooled cylinder heads and crankcase, will be employed in the test setup.

The source water loop is intended to simulate "white water" from a paper machine at temperatures between 60°C and 80°C.

The thermal stability of R113 and synthetic refrigerant oil in the 120°C to 145°C temperature range will be investigated as well as the durability and performance of available compressors and refrigeration components subjected to the same high temperatures.

The output from the research will hopefully identify the technical feasibility of

raising steam with heat pumps in the Pulp and Paper industry.

The non-azeotropic refrigerant mixture research will attempt to identify a refrigerant pair(s) ideally suited to high temperature heat pump application Initial screening of candidate pairs has resulted in R12/R11 being selected for investigation. Concentrations will be varied between 30 and 70 percent of either constituent.

Although R12/R11 appears to be thermodynamically the best selection, current controversy surrounding the impact of fluorocarbons on the ozone layer has targeted both for extinction. This could have serious implications on future research efforts.

Past research work in non-azeotropic refrigerants has failed to optimize heat transfer design or surface areas or other component selection to accommodate mixtures. NRC plans to do this in their research program.

Initial performance (COP) tests will be undertaken on a water-to-water heat pump of nominal 2 or 3 ton capacity using R12. This will be followed by direct substitution of various concentrations of R12/R11. Finally, changes in heat transfer surface areas and heat exchanger design to optimize COP will be evaluated. This last phase is important to take advantage of '*sliding*' temperature gradients inherent with refrigerant mixtures.

In addition to the design and testing work, further analytical work will be undertaken to predict properties of various refrigerant mixtures and perhaps identify promising refrigerant pairs for future consideration.

Ontario Hydro [8]

The Process Applications Unit, Utilization Section, Ontario Hydro Research Division, have established a research activity to provide technical assistance to industrial customers to help identify new applications for heat pump dehumidifier technology.

A product drying-rate facility has been operational since 1985, providing data to customers not normally available but necessary to determine what benefit if any can be gained from application of dehumidification drying.

A sample of customer product is tested in an environmental chamber to determine drying-rate as a function of temperature and humidity conditions. The drying-rate, obtained in this way, is then compared with performance characteristics of commercially available dehumidifiers. Optimization of the

drying process is made by searching for a minimum drying time or energy use or capital cost as specified by the customer.

Various products have been evaluated including fresh fruit slices and fruit peels. These efforts have identified areas where a processor can produce additional revenue and reduce waste handling costs, as well as reduce drying energy cost in comparison to conventional heat-and-vent methods.

Ontario Hydro Research are also involved in undertaking technical feasibility assessments of heat pump applications for industrial customers and can provide third party field performance monitoring to develop case studies of industrial equipment installations.

Energy, Mines and Resources Canada (CANMET)

Energy, Mines and Resources Canada's, Energy Research Laboratories (CANMET), continue to fund a number of industrial heat pump activities initiated by the former Division of Energy, National Research Council of Canada.

Investigations of non-azeotropic refrigerant mixtures as applied to heat pumps are partially funded by EMR CANMET at both the Division of Mechanical Engineering, NRC and at Centre de Recherche Industrielle du Québec (CRIQ). These activities were described earlier.

Another heat pump research area, outside the scope of this investigation, being funded by EMR CANMET is the feasibility of chemical reaction and absorption heat pumps in the pulp and paper and refining industry. Acres Consulting Services are refining mathematical modelling of chemical reaction heat pumps using xeolites and sodium hydroxide. The Universities of Toronto and Ottawa are involved as subcontractors. Delta Engineering are investigating the potential for absorption heat pumps in the refining industry. The research was started originally by Stearns Catalytic under contract to the Division of Energy, N.R.C. Stearns Catalytic are now a unit of Delta.

At present, EMR CANMET are holding discussions with AECL and its CANDU group about the technical feasibility of employing heat pumps to upgrade cooling water from Slow-Poke reactors to provide hot water for district heating applications.

Pulp and Paper Reseach Institute of Canada (PAPRICAN) [9]

PAPRICAN is currently assessing the technical and economic feasibility of various steam generating heat pump applications for waste heat recovery in thepulp and paper industry.

PAPMOD is a computer simulation model of a newsprint mill originally developed by PAPRICAN to predict mass and energy flows in a mill. PAPMOD is a steady-state, modular program designed to be run with a variable number of flow components with various process models. A user can start with a simple process representation and add refinements as knowledge of the process improves.

A simplified high temperature heat pump (HTHP) model has been developed and added to PAPMOD to assess the feasibility of heat pump integration into a paper mill. The HTHP consists of an R114 heat pump with subsequent upgrading of the resulting steam by a mechanical or thermal vapour recompressor.

One application assessed, so far, involves the integration of the HTHP into a paper mill's white-water system. Heat was recovered from the white-water stream (60°C) by the R114 heat pump. The resulting 110°C steam enters a mechanical vapour compressor and is raised to 140°C (about 50 psia) steam suitable for the paper dryer operation. In comparison to steam generated by conventional means at a cost of $5 per gigajoule, the HTHP exhibited a payback period of about 7 years with an after-tax discounted cash flow return on investment of 9.5 percent.

PAPRICAN's efforts to-date indicate the need for more acceptable working fluids (possibly methanol or R113) which could reduce the cost of the HTHP and improve efficiency of energy recovery.

4. TECHNICAL DIFFICULTIES WITH EARLY INSTALLATIONS

A number of industrial heat pumps were planned and implemented between 1981 and 1984 cofunded by industry and the National Research Council's Heat Pump Program. These installations were some of the earliest in North America. At such an early stage of a technology's development, the level of skills in equipment design, application and operation are bound to be low.

The discussion of technical difficulties is based on operating experience of industrial heat pumps [10], [11] of the same make (Templifier) in the same application (boiler

feedwater heating) in the following industrial plants:

- Agrinove Dairy, Ste. Claire, P.Q.;
- Monarch Fine Foods Limited, Rexdale, Ont.;
- Brunswick Mining and Smelting Corp., Belledune, N.B.;
- Canadian International Paper Inc., Gatineau, P.Q.

Complete details on these installations can be found in Reference [12].

The most significant problem common to each of these installations was a direct result of operating transients (flows and temperatures of source and sink) which were either not foreseen or inadequately accounted for in the system design. The heat pump compressors were simply unable to track the load variations resulting in nuisance trips on overloads and in some cases compressor motor failure.

The heat pump system at Monarch Fine Foods was subjected to flow rate variations of up to a factor of two, both in the cooling water (heat source) and the boiler feedwater (heat sink). Cooling water flow from batch operations resulted in stepwise changes in heat source flows ultimately resulting in one compressor failure.

At Brunswick Mining and Smelting, similar flow variations were experienced shortly after start-up. A recirculation line for the boiler feedwater make-up was installed to prevent sharp drops in the flow of the boiler feedwater passing through the heat pump condenser.

At Canadian International Paper Inc. (C.I.P.) nuisance compressor shutdowns were experienced due to large fluctuations in both temperature and flow rates of both the boiler feedwater and the "white" water. To avoid these unbalanced conditions, water preheated by the system in excess of boiler feedwater requirements was sent to a reservoir for later use in one of the paper machines. To avoid low "white" water flows on the evaporator side and attendant compressor stoppages an additional "white" water reservoir within the plant was connected to the white water supply to the heat recovery system.

Both the Monarch Fine Foods and C.I.P. installations had difficulties resulting from refrigerant migrating to the crankcase, mixing with the lubricating oil, leading to difficulties in restarting the compressor following equipment shutdowns. C.I.P. modified the lubricating oil heating/cooling system to maintain the oil temperature well above the temperature of the entering "white" water to avoid refrigerant migration start-up problems.

The C.I.P. installation also experienced severe fouling problems on the fresh water side of the heat exchangers. (Spiral heat exchangers had been specified to avoid potential fouling on the "white" water side.) Chemical treatment solved the problem.

However, later, refrigerant pressures mysteriously dropped over a period of time. Close inspection revealed that the copper condenser tubes had a myriad of small holes, obviously the result of corrosion. The condenser was subsequently retubed with stainless steel.

Despite the initial difficulties, three of the four installations remain operational to this day. The Monarch Fine Foods Ltd. heat pump was permanently valved out of the heat recovery system in August of 1985. Ontario Hydro have subsequently purchased the unit and plan to reactivate it at their research facility in Toronto.

The Canadian Electrical Association is funding Ontario Research Foundation to update the status of these four heat recovery heat pump installations along with eight others. The investigation involves reviewing the operational experiences/problems encountered and to propose solutions to outstanding problems.

5. CONCLUSIONS

Current Research Activity

Research activity in the United States has shifted from an emphasis on exclusively technology development (for limited applications) in earlier years to more emphasis on identifying the proper placement of heat pumps in industrial processes (application of 'Pinch' Technology). This new approach seems more rational and will no doubt lead to identifying cost-effective applications for both open and closed-cycle electrically driven heat pumps.

In Canada, there is no longer a central organization planning, co-ordinating, undertaking and/or funding industrial heat pump research and development. Activities are spread throughout Canada, with communication and attempts at co-ordination through the National Heat Pump Co-ordinating Committee. Without significant funding, however, the Committee cannot adequately sustain a rational industrial heat pump components and applications R & D program.

Technical Difficulties with Early Installations

Early electrically driven closed-cycle heat pumps applied in waste heat recovery applications in industry were plagued with equipment breakdowns. The current C.E.A. investigation of twelve installations (including three electrically driven MVR systems) should provide a means of viewing the heat pump in use and provide valuable information to improve on, or better identify, future applications.

6. RECOMMENDATIONS

It is doubtful that Canada can support development and manufacture of large electrically-driven industrial heat pump equipment (particularly compressors) and hence research efforts should concentrate on identifying, demonstrating, or increasing awareness of appropriate applications of existing technology.

'Pinch Technology', for process synthesis, shows promise of being able to identify suitable heat pump applications in industrial processes. This approach, if applied to analyze the industrial processes in Canada to which the demonstration heat pumps were ultimately applied, may very well have pointed out that the specific sites were unsuited to heat pump application. Process synthesis efforts are warranted to ensure successful applications in the future.

Very little is known at this time about the potential for MVR system application in Canadian industry. The ten installations estimated to be in Canada, at this time, were installed by industry without incentives. The MVR evaporators are currently applied in the sweetner, pulp and paper, fertilizer, food processing and dairy industries in concentration processes. In some cases, they represent the lowest capital cost alternative, in others, the far superior energy performance (C.O.P.'s greater than 10) more than offsets the additional capital cost resulting in short payback periods. Development of case studies and investigations to identify promising concentrating processes in other industries could accelerate the adoption of this energy efficient technology.

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APPENDIX 1

SURVEY OF R & D FUNDING AND PERFORMING ORGANIZATIONS

Current Research and Development Activity

Organization: United States Department of Energy
Industrial Programs Office

Contact: Mr. Scott Richler
Program Manager
Industrial Heat Pumps
(202) 586-2078

Current Research and Development Activity:

- DOE started industrial heat pump program in 1978 with projects involving three developments:
  - Mechanical Technology Inc. - waste heat powered steam compression system intended to extract heat from waste steam to produce clean steam;
  - Westinghouse Electric Corp. - high temperature electrically driven Rankine system with methanol as the working fluid for extracting heat from waste steam to produce clean steam;
  - AiResearch Manufacturing Company - Brayton cycle solvent - recovery system to recover solvents from airstreams in drying ovens, restore the heat of vaporization to the airstream and return solvent-free air to the drying oven.
- Field tests on M.T.I. and Westinghouse prototypes were never undertaken.
- The heat pumps that have been installed in industry in the U.S.A. are of two kinds - those that work and those that don't work.
- They don't work because of poor plant management and transients of operation.
- The industry has to be smarter in application.
- D.O.E. activities at Idaho center on magnetic cycle heat pump.
- Currently developing a gallium plated heat pump.
- Also, heat of reaction - chemical heat pump.
- No MVR research being supported.
- The utilities are promoting that technology.
- Lumber drying applications are popular in the U.S.A.
- In the "advanced applications" area good installations need to be supported by case studies to provide evidence to other potential users - D.O.E. not undertaking demonstrations at this time.
- No research and development efforts in alternative refrigerants.
- The D.O.E. Heat Pump Program is in a transition stage at this time.
- Research efforts are attempting to identify the proper use for the heat pump in industry.

Organization: United States Department of Energy
Idaho Operations Office
Idaho Falls, Idaho

Contact: Mr. Robert Chappell
(208) 526-0085

Current Research and Development Activity:

- Performance testing on the three large developments by M.T.I., Westinghouse Electric and AiResearch are complete and reported on.
- Field performance assessment was not undertaken because industrial host sites fell through.
- Hydro Québec elected not to install the Westinghouse Electric unit because of patent restrictions.
- The Brayton Cycle unit developed by AiResearch will be installed in a 3M plant in May 1987.
- The three units were all originally designed for specific application in specific plants.
- Heat pumps in industrial sites were the darlings of the 1970's - damned in the 1980's.
- Early on, heat pumps were mainly intended for heat recovery applications.
- The 3M installation is really a refrigeration application with solvent recovery from a tape drying oven.
- Early failures in heat recovery applications sent the fortunes of the heat pump downhill.
- The heat pump was simply not effective in most heat recovery applications.
- D.O.E. decided to look at heat pump's role in certain processes - went to the process synthesis industry for guidance.
- Both the D.O.E. and EPRI are coordinating efforts in process synthesis.
- There are three different configurations - semi-open cycle (one heat exchanger between process fluid and working fluid); open cycle (MVR) (process fluid is working fluid); closed cycle (refrigerant working fluid).
- The open cycle is the most economical to operate in aqueous processes (high COP).
- D.O.E. is also looking at different thermodynamic cycles, i.e. chemical reaction

rather than phase change.

- *Mechanical heat pump COP limited by temperature and materials in system.*

- Chemical heat pumps are not constrained by temperature/material considerations and therefore more closely approach Carnot COP.

- At present, temperatures are very low (standard absorption - 300°F) and research efforts should be able to push chemical heat pump operating temperature limits upward.

- Rocky Research, Boulder City, Nevada are currently working on a new chemical heat pump, with no moving parts - long term research.

- No research in alternative refrigerants for conventional closed-cycle equipment - not needed - 250°F is possible with current refrigerants.

- Not aware of any "fundamental or earth shattering research" underway in the U.S.

- <u>R & D "wish list"</u> 1. a successful demonstration of the Brayton Cycle unit in the 3M solvent recovery installation; 2. need to get a few good industrial heat pump installations in place, properly integrated into a process - reductions of up to 50 percent in process energy should be possible; 3. other chemical heat pump cycles should be investigated; 4. magnetic heat pumps show promise - magnetics are improving - superconductivity is being achieved at higher and higher temperatures particularly in last few years.

Organization: Electric Power Research Institute
Palo Alto, California

Contact: Mr. Alan Karp
(415) 855-2548

Current Research and Development Activity:

- E.P.R.I. have a number of ongoing heat pump research projects within their Industrial Program - Process Industries area:

  - RP2220-01 - Hybrid High COP Heat Pump Application Study
  - RP2220-02 - Heat Pumps in Evaporation
  - RP2220-03 - Heat Pumps in Complex Heat and Power Systems

- The focus study at this time (RP2220-02) is attempting to develop application guidelines and case studies of electric-driven MVR's in evaporation processes in the chemical, petroleum, textile, pulp and paper, dairy and food industies.

- Developing a screening process (RP2220-03) i.e. procedure and software to identify heat pump opportunities in complex heat and power systems characteristic of the process industries.

- An assessment (RP2220-01) of the potential technical and economic markets for a hybrid (either waste heat or electrically driven) heat pump and identification of potential industrial demonstration sites. (This unit originally developed under funding from D.O.E. by M.T.I.).

- E.P.R.I. concentrate on "generic research" and do not undertake product development per se.

- Plan to implement the development of case studies of installations resulting from the projects cited above.

Organization: Division of Mechanical Engineering
National Research Council of Canada

Contact: Mr. J. Linton
(613) 993-2371

Current Research and Development Activity:

- The Division of Mechanical Engineering is constructing a pilot scale steam generating heat pump (R113) with a thermal output capacity of about 40 kW to investigate the following:

  - the thermal stability of R113 and synthetic refrigerant oil in the 120°C to 145°C range of condensing temperatures;

  - the durability of available industrial compressors and refrigeration components to withstand very high temperatures;

  - the performance (COP) at different source and sink temperatures; [condensing - 120°C to 145°C , evaporating - 50°C to 75°C]

  - the source water loop is intended to simulate "white water" (from a paper machine) at temperatures between 60 and 80°C;

  - a 12.4 BHP reciprocating Mycom compressor (with water cooled cylinder heads and crankcase) will be used in the test setup;

  - the output from the research will hopefully identify the steam raising potential of heat pumps with the target application in the Pulp and Paper industry.

Organization: Division of Mechanical Engineering
National Research Council of Canada
Contact: Mr. K. Snelson
(613) 993-2371

Current Research and Development Activity:

- The Division of Mechanical Engineering (DME) are proposing to continue investigations initiated at C.R.I.Q. to evaluate potential of non-azeotropic refrigerant mixtures.
- The emphasis will be to identify a refrigerant pair(s) ideally suited to high temperature heat pump application (ultimately direct steam generation).
- NRC have decided to concentrate investigations on R12/R11 mixtures in concentrations varying between 30 and 70 percent of either constituent.
- R12/R11 appears to be thermodynamically the best selection - environmentally (ozone controversy) not sure.
- Performance will eventually be verified on the steam generating heat pump test rig.
- Past research work in non-azeotropic refrigerants has failed to adequately optimize heat transfer areas or other component selection and design to accommodate mixtures - NRC plans to do this in their programs.
- Performance (COP) data with R12/R11 mixtures will be compared with other high temperature refrigerants (perhaps R12).
- Initial tests will be undertaken on water-to-water heat pump of nominal 2 or 3 ton capacity using R12, followed by various concentrations of R12/R11, followed by changes in heat transfer surface areas and heat exchanger design to optimize COP and to take advantage of "sliding" temperature gradients inherent with refrigerant mixtures.
- The experimental work will be supported by further analytical work at DME predicting properties of various refrigerant mixtures.

Organization: Ontario Hydro
Research Division

Contact: Mr. Terry Strack
(416) 231-4111
Ext. 6723

Current Research and Development Activity:

- The Process Applications Unit, Utilization Section, Ontario Hydro Research Division have established a product drying-rate measuring facility to enable heat pump dehumidification dryer performance to be optimized.

- A customer provides Ontario Hydro with samples of product for evaluation.

- In an environmental chamber drying rate measurements are taken at various temperature and humidity conditions as the product drys.

- Once the product drying characteristic is known it is matched to the water-extraction characteristic of various commercially available dehumidifiers.

- System optimization involves searching for a minimum in one parameter (eg. drying time, energy consumption, capital cost) as desired by the customer.

- Product evaluated in the facility to date include textile, paper and food products including fruit slices.

- The specific energy consumption of dehumidification dryers is considerably lower than by conventional heat and vent methods. For example, in the fruit slice drying experiments an energy consumption of .86 kWh/kg of water removed compares with 2.1 kWh/kg of water removed for conventional drying.

- Ontario Hydro hope to expand the markets available to dehumidification dryer manufacturers by developing the information on how products dry and bringing the manufacturer and customer together.

Organization: Energy, Mines and Resources Canada
Canmet

Contact: Mr. M. Wiggin
(613) 998-7912

Current Research and Development Activity:

- The National Research Council and C.R.I.Q. will continue to collaborate on the non-azeotropic refrigerant mixtures area with some funding from EMR.

- John Smale (Dupont Canada Inc.) and Michel Boulander, C.R.I.Q. are Canada's representatives on the I.E.A. Advanced Heat Pump Annex on refrigerant mixtures. Canada has joined the annex with a contribution being the results of work undertaken by C.R.I.Q. In return, Canada gains access to previous annex output on non-azeotropic refrigerant mixtures.

- Acres, with the University of Torontoand University of Ottawa as subcontractors, have a contract with EMR to refine the mathematical modelling of chemical reaction heat pumps. Xeolite and sodium hydroxide are being examined as potential candidates. The application being examined is pulp and paper drying.

- The application of chemical heat pumps to distillation columns is under investigation by Delta Engineering. The work was initiated by Stearns Catalytic for the former Heat Pump Program at NRC. Stearns were recently acquired by Delta and EMR continue to fund the project.

- EMR are holding discussions with AECL and its CANDU group about the possibility of upgrading cooling water from Slow-Poke reactors by employing heat pumps. A district heating scheme might be the application.

Inquiries concerning the report content can be obtained by writing to the above address, or by contacting Jack Klieb at (416) 965-8424. Toll free long distance call Zenith 80420.

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